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Over Eight Decades Old “Young” Landslide – A Case Study

Kishor Kumar
Central Road Research Institute, India

P. S. Prasad
Central Road Research Institute, India

Anil Kathait
Central Road Research Institute, India

Indervir Singh
Central Road Research Institute, India

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Kishor Kumar
Central Road Research Institute
New Delhi-India 110025

P. S. Prasad, Anil Kathait and Indervir Singh
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ABSTRACT

Shirobagad also named as Kaliasaur Landslide was developed in the year 1920 at kilometer-147 on National Highway – 58 (earlier named as State Highway - 45) at latitude 300 14' 30" N and longitude780 53' 57" in Garhwal region of western Himalaya. This landslide has been investigated by a number of organizations in India and a wealth of data has been generated mainly on geological aspects. Central Road Research Institute has also investigated this landslide during 2007-2011 covering geological as well as geotechnical aspects. The study area basically encompasses metavolcanis and variants of quartzite rock (e.g. pink and white quartzite) with occasional bands of shale. Frequent presence of displacement along structural planes, offsetting of beds, omission and re-appearance of the strata, and change in the attitude of structural planes illustrates the presence of a series of minor faults, it includes contact between litho units drainages etc. Having observed these geological features and many more others the study has further included micro analysis and observations based on Rock mass rating and Slope mass rating, monitoring of slope behavior through simple but reliable, especially designed steel pedestals, Differential Global Positioning System and Total station etc. The minute geological observations added with behavior monitoring and geotechnical backup has been able to decipher the most important causes of the landslide and therefore most suitable remedial scheme which shall be discussed in the paper.

INTRODUCTION

Kaliasaur landslide, aging more than eight decades (1920 2012) and still acts as a panic disaster on National Highway – 58 (Fig 1). Periodic activation of this slide has changed the topography of the area to that extent that it always looks like a young slide. It is one of the complex slope failures, a combination of slide, fall and flow. At early stages of its development the slide enlarged progressively, where the slide has grown all through its boundaries. When the crown of it has reached to an altitude of around 800m, it has enlarged retrogressively, where only its crown part has got enlarged. In the year 1984 the crown was at 805m which has increased to 845m until 2012. The Most recent devastating events of its activation has been during July-September 2010, huge amount of material discharged from the slide has completely covered the highway for 95 meter length (Fig 2). The highway was blocked for 45days and intermittently for five months. As the highway links this part and holiest pilgrimage hubs of this area namely Badrinath, Kedarnath, Gangotri and Yamnotri with rest of the country, millions of tourists from all over the world visit each year (May-November). The Highway was blocked at this point almost every year since 1984 for few hours to several days depending upon the magnitude of the slide. The recent event of sliding in August 2010, part of the peak tourist season, fortunately begun in the night when there were no vehicles on the roads because in the night traffic is not allowed in hilly areas during tourist seasons. The blockade of highway this time has been the longest and

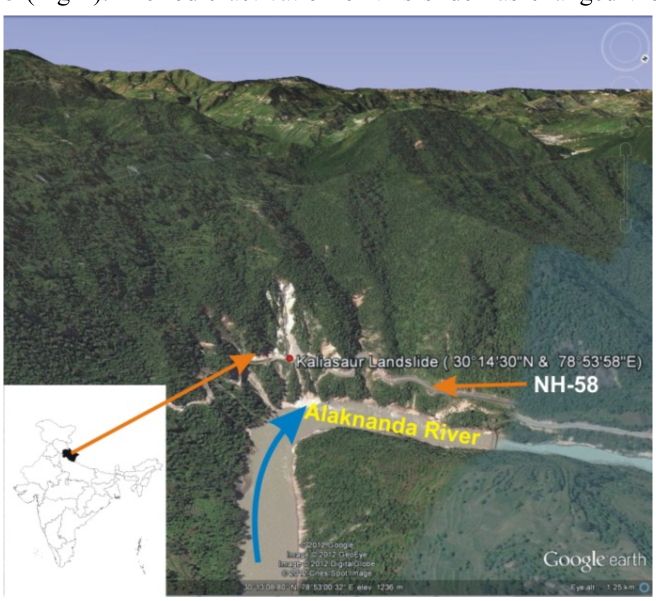

Fig. 1. Location of Kaliasaur Landslide on NH-58

Fig. 2. Metamorphosis of Kaliasaur Landslide Year by Year

nightmare for the visitor, the local commuters, police, military and the maintenance agencies like Border Roads Organization (BRO). In spite of good work done by BRO, two people have lost their life and a few have been injured, also two vehicles crushed under the rubble. There was confusion and panic amongst the people about their journey. Millions have been waiting for restoration of traffic for tens of days before deciding to follow some other alternatives. Two alternative routes, although risky and economically disadvantageous have been chosen by people on their own choice in emergency situation.

The study area mainly comprises of metavolcanis and variants of quartzite rock in pink and white color with occasional bands of shale. Quartzite, in normal conditions, is a hard rock of 90 to 140 N/mm^2 but at the slide location the same is fractured with varying intensity ranging from moderate to the extent that it give the impression of white powder. Shale being the weakest member of the rocks and intercalating between the quartzitic members have been weathering and eroding quickly providing quartzite rocks to topple/slide/fall. Dykes of volcanic rocks intruding the quartzite also have been playing almost the same role. Presence of a series of minor faults, including contacts between litho units and drainages have made the slope inherently susceptible to failure. This paper describes the detailed geological, geomorphological, geotechnical investigation, instrumentation and monitoring, detouring cost and suggested remedial measures.

GEOLOGICAL RELEVANCE TO SLIDING

As per regional geological studies the whole area broadly belongs to Lesser Himalayan divisions and while the rocks of this area come under one of its stratigraphic groups "Garhwal Group". This Group, in the Upper-middle and Lower parts of Alaknanda valley, is represented by a number of formations (Kumar and Aggarwal 1975) and the study area belongs to Rudraprayag Formation. The lithostratigraphy of the Rudraprayag Formation suggests that it belongs to an Argillo-arenaceous facies.

It is further divided into five members viz. Uttyasu Quartzite Lameri Member, Haryali Quartzite, Thalasu Schistose Grit, and Karanprayag Metavolcanics. The slide area consists mainly of Uttyasu member.

The lithological variations within and outside the slide area are not many. The whole area is dominated by quartzite and occasional layers of slate and metavolcanics. It is generally notice that the contacts between two litho units including between pink and white quartzite are often a fault (Fig 3).

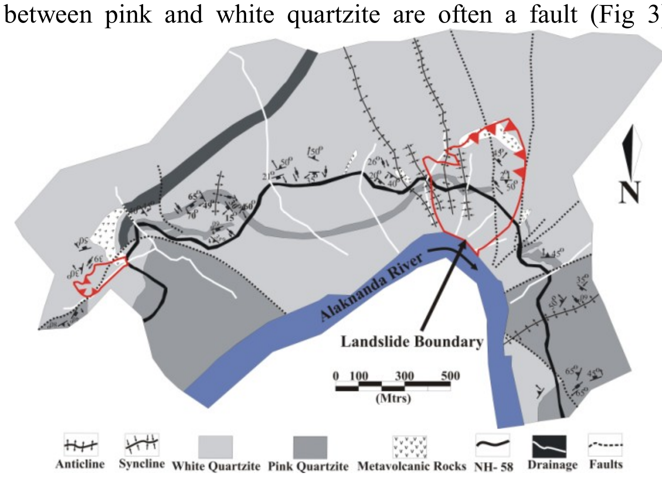

Fig. 3. Geological Map of Kaliasaur Landslide

Other evidences of fault to mention are: most of the drainages are parallel or sub-parallel to the faults, which depict the role of structural deformation in shaping the morphology of the terrain (CRRI report 2009) and displacement along the dykes. Folding observed in the quartzite has also been associated with the displacement at places. The rocks are highly jointed, fractured and friable and wedge failure is the most common mode of failure in the area (Fig 4). The existing main vertical

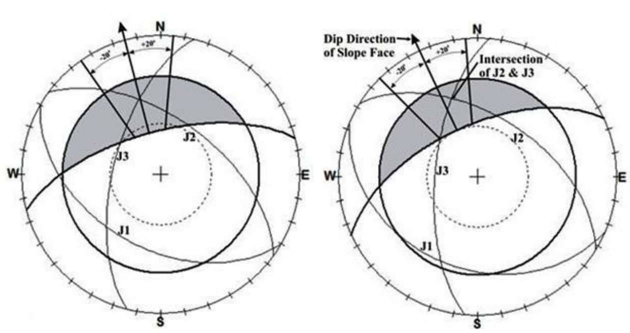

Fig. 4. Markland Test Shows Satisfied Conditions for Wedge Failure

scar below the crown has distinct contact between highly fractures quartzite and highly weathered metavolcanic rocks which are vulnerable to further failure in coming monsoon (Fig 5).

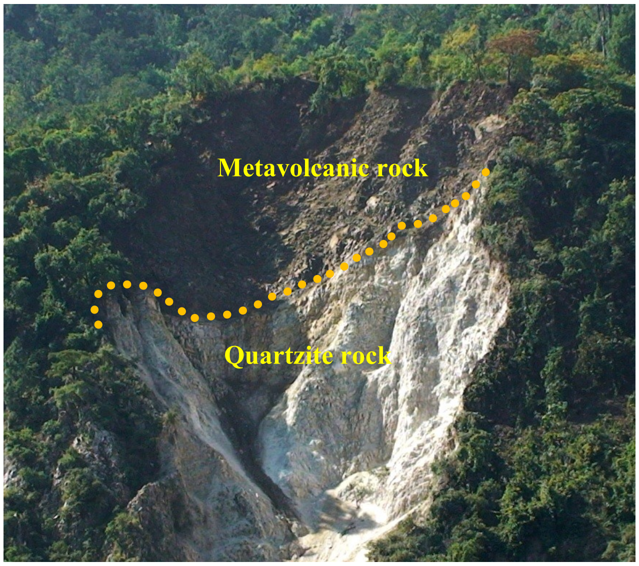

Fig. 5. Contact between Metavolcanic and Quartzite Rocks

GEOMORPHOLOGICAL EVIDENCES

The repeated landsliding activity particularly since 1984 has manifested in changing morphology of the slope. This also gives an idea about the magnitude of its probable changes in the future. The main sliding body above the National Highway (Fig 6) which was mostly concavo- convex, extending about

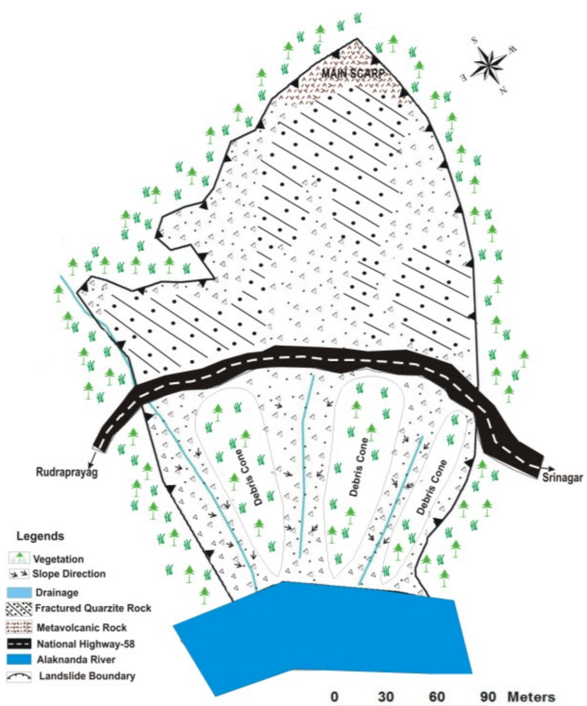

Fig. 6. Geomorphological Setup of Study Area (Pre 2010)

198m (from road to the crown) during 2005-2009 has transformed into mostly convex slope because of the recent landsliding in the year 2010 (Fig 7). The lower portion of this

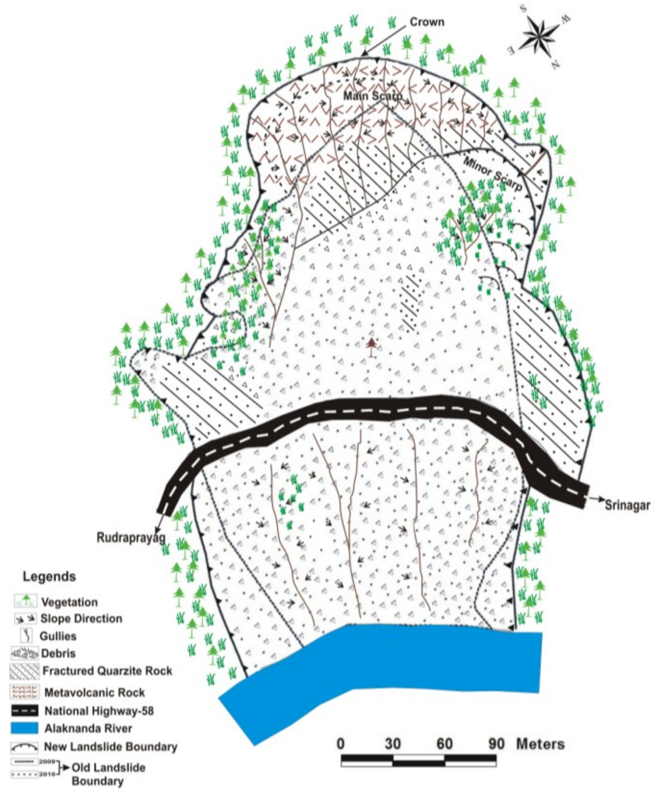

Fig. 7. Geomorphological Setup of Study Area (After 2010)

slope part just above the highway, ranging earlier 35^0 - 45^0 changed to 40^0-50^0 and measured about 104m has extended to 120m. This acts as zone of deposition of debris generated by the sliding of highly fractured strata from the crown/cliff part of slide. The debris mainly consists of fragments of quartzite, metavolcanics and gauge material of particles ranging from clay to boulder of 0.5 mm dia. Since the debris generation is almost a continuous process; this part mostly remains destabilized. The slope is almost devoid of vegetation, which otherwise might have proved helpful to stabilize the slide. The cliff houses highly disintegrated rocks, quartzite and metavolcanics; quartzite rock is in the form of fine gauge material of varying particle sizes which has very low strength. Metavolcanic rock, on the other hand, is more weathered and sometime to the extent that it is confused with clay. During reactivation of slide in 2010 the main scarp between crown and displaced material developed a number of deep and wide gullies (Fig 7) of 0.5m to 1.5m deep and 0.75m to 3.5m wide, providing scope of further negative impact due to water. This steepest slope consisting of highly disintegrated and low strength material/rock, exposed to intense weathering and erosion due to rain water as well as high speed wind. Above the crown, the convexity of the slopes continued to be followed up to 125m wherefrom it transforms into concavo straight slope until the village Chantikhal (Fig 8). All along the highway, both side of the active landslide limits the

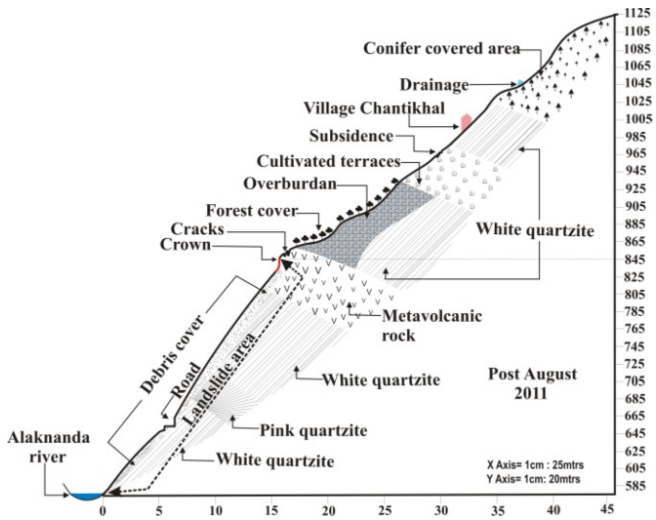

Fig. 8 . General Cross Section across Kaliasaur Landslide Representing Lithological Distinctions, Shape of Slope and Topographic Features Present on the Slope.

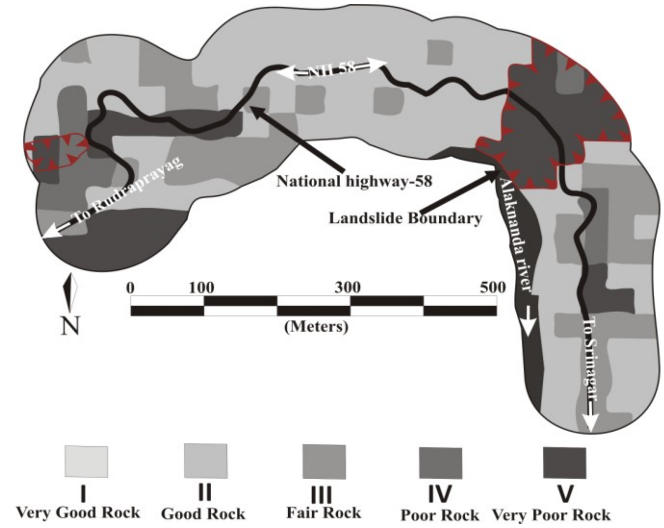

Fig. 9. RMR of Study Area

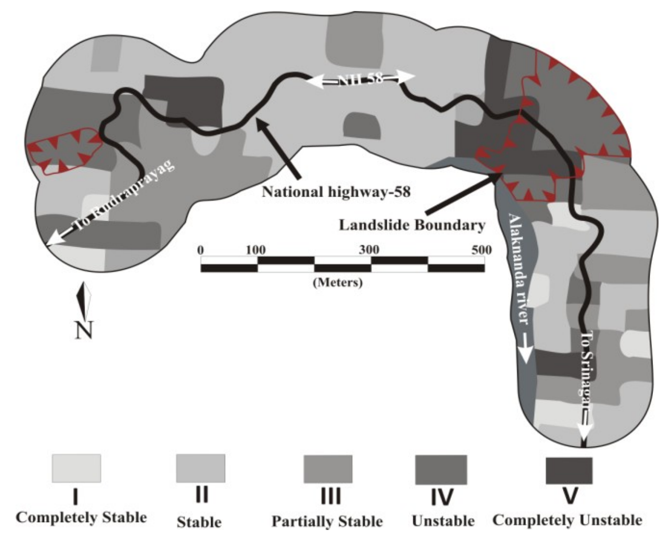

Fig. 10. SMR of Study Area

vertical cut slopes are vulnerable because of the jointed rock mass, intercalation of weaker strata, minor faulting, unprotected rocky slopes and continuous erosion and weathering. Below the road there were three debris shoots alternating to three elevated dividers (fig 6) pre 2010 slide have been disappeared because of the accumulation of excess amount of debris (Fig 7).

VULNERABILITY ANALYSIS BASED ON ROCK & SLOPE MASS CHRACTERISATION

The study area was divided into 197 grids of equal size (45m*45m) along the National Highway-58 for the slope stability analysis based on rock mass and slope mass characterization. Detailed structural mapping was carried out (based on exposures of the rocky outcrops) for the data on rock types, their attitude and quality condition i.e. weathering conditions. The type of failure was assessed on the basis of stereographic analysis of discontinuities (CRRI report 2009). The results made it evident that rock mass quality was significantly affected by weathering and alteration of rock mass, as the rock mass falling in weak range of rock mass characterization was invariably associated with weathered zones. It was observed that rock mass falling under class I and II of RMR did not show failure whereas class III, IV and V were involved in sliding (Fig 9). Similarly range I and II of SMR were not in failure zone whereas rest of the classes has come under failure zones (Fig 10).

MICRO-HAZARD EVALUATION OF KALIASAUR LANDSLIDE SLOPE

The objective of this evaluation was to prepare a hazard potential map of the slope. A large scale (1:500) topographic digital base map was prepared prior to the detailed geological, geomorphological and geotechnical mapping and investigation. All subsequent field mapping was carried out in the same scale in digital mode using GIS tool. Thereafter the map was divided into grids measuring 45m x 45m, to individually study each grid for a realistic and accurate evaluation of stability of the slope and forecasting the type of possible failure for each of the grids (Kishor et.al 2012). Following the above mentioned methodology each grid has been classified into different zones of potential landslide hazard. These grids with their landslide hazard potential have been utilized to develop a landslide hazard map of the whole area. Stability has also been assessed for rock slopes of the area by quantifying the various parameters viz. lithology, structural relationships, slope gradient, landuse/ landcover, and water conditions that define the susceptibility of slopes to failure, for each of the grids of the study area (Fig 11).

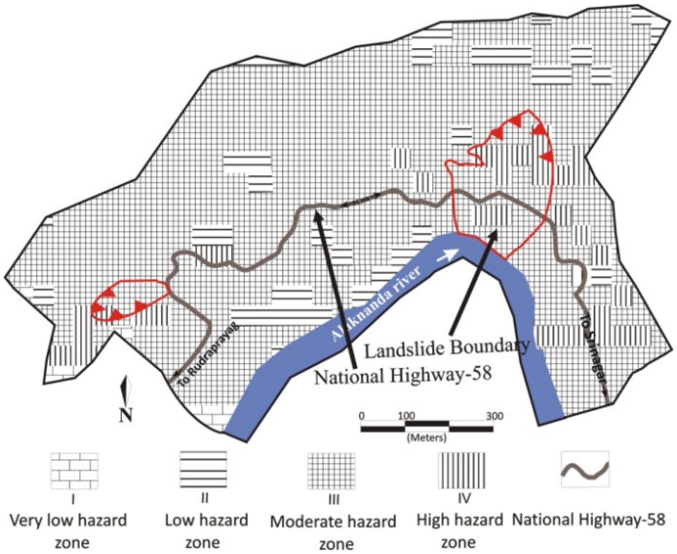

Fig. 11. Micro-Hazard Zonation Map of Kaliasaur Landslide

The Micro LHZ map developed indicates three levels of hazard, low, moderate and high (II, III, & IV). Low hazard zones represent currently stable slopes whereas the maximum area is covered under the moderate degree of hazard representing the slopes that are not stable and may fail as soon as any of the triggering factors come into play. Several zones are marked by high degree hazard indicating the slopes that are not stable and have already failed. Total estimated hazard value, obtained by adding the individual ratings of all the parameters, varies between 3 (medium) and 8 (high) which are descriptive zones of moderate to high hazard. The Micro – Hazard Zonation Map (MHZM) has clearly indicated the presently affected areas under high hazard. The results have been justified in the field and found worth recommendation.

SIMPLE & ECONOMICAL MONITORING OF LANDSLIDE AREA

75 numbers of specially designed steel pedestals have been installed at identified locations on the slope of landslide for monitoring the deformation, if any. The initial positions of the pedestals installed on the slope have been plotted on the contour map. After fixing the position of each pedestal with the help of DGPS, the second time monitoring was done after the monsoon. This was followed by the third time monitoring & so on.

Monitoring of pedestals revealed that out of 75 pedestals only a few have experienced significant amount of movement ranging from 1.74m to 3.69m. The movement of the pedestals monitored through Differential Global Positioning System (DGPS) is presented in table 1. It was noticed that the

Table 1 Pedestals showing significant movement on the slope

Pedestal No.	Initial Position	Second Position	Third Position	I - S	S - T	Resultant	Dir
Kn 2	899.2	897.5	895.5	1.72	1.93	3.64	N-E
Kn 3	902.6	900.9	899.3	1.73	1.52	3.26	N-E
Kp 11	669.2	667.5	666.1	1.69	1.43	3.13	N-E
Kn 13	658.7	657.6	656.2	1.18	1.38	2.56	N-E
Kn 16	658.7	657.5	656.6	1.14	0.95	2.1	N-W
Kn 19	662.5	660.6	659.2	1.87	1.48	3.36	E
Kp 21	819.9	818.1	816.1	1.78	2.0	3.78	N-E
Kn 23	640.3	638.8	637.1	1.48	1.69	3.17	N-E
Kn 26	656.0	654.4	653.0	1.61	1.41	3.02	N
Kn 28	653.4	652.7	651.7	0.77	0.97	1.74	W
Kp 29	818.6	816.9	815.4	1.67	1.48	3.15	N-E
Kp 32	705.9	704.2	702.2	1.74	1.95	3.69	N-E

pedestals installed within the slide boundary did not indicate much of the movement except at only two locations. These two locations are on the loose debris deposition. Rest of the pedestals which have shown movements were located near and above crown part indicating active movement above it only. These results found coinciding with the activity of slide which was mostly confined to above the crown part. Pedestals spread much beyond the crown up to Chantikhal village have also shown some movement. Since none of the pedestals shown upwards tilting, no indication of deep seated movement was assumed.

The movement of the pedestals on the slope was found directly in correlation with the rainfall. This landslide gets reactivated during every rainy season but the intensity of the slide varies depending upon the amount and duration of the rainfall (Fig 12). Rainfall amount in this area have been found varying in different months of the year. Most of the rainfall received during June to September. In the month of June-September, 2010, rainfall broke all the records of past 5 years (504.8 mm average) which was sufficient to reactivate the sliding.

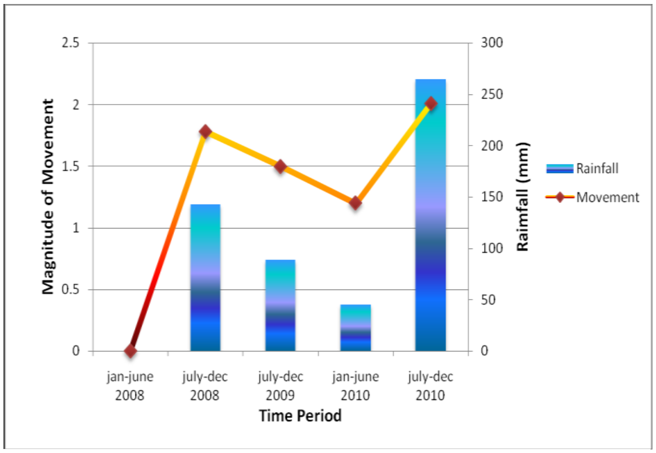

Fig. 12. Graph Showing Magnitude of Movement against Rainfall

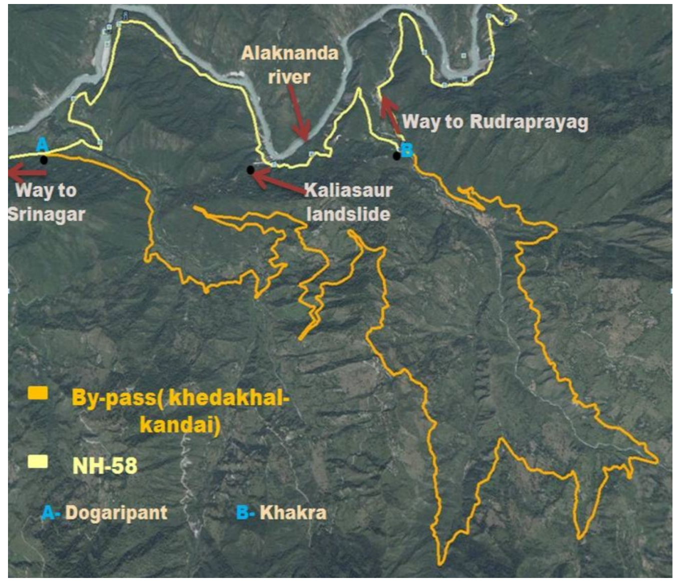

Fig. 13. View of Kaliasaur Area Depicts by-pass from Dogaripant to Khakra

ESTIMATION OF INDIRECT LANDSLIDE LOSSES

Landslide are responsible for considerable socio – economic losses than is generally recognized and because of their socio economic implications as well as the scientific interest, these can be considered as a problem of greater relevance (Khire 2004, L. Cascini et al 1992 and Kishor Kumar et al., 2010). Landslide damages are often reported as a result of a triggering event like an earthquake or an excessive rainfall episode (Spiker & Gori, 2003), which can be represented by purely economic costs (Glade, 1998). The overall costs of landslides include both direct and indirect costs.

In the study area, we have used unit cost estimation method to estimate the cost of the indirect landslide losses related to the highway closure during September-October, 2010. This method is applicable whenever a unit variable is known (i.e. no. of days an area is affected) and the associated unit cost (i.e. loss per day) can be determined. A general equation for this approach is as follows:

Detour cost= (Extra operating costs in detouring + Extra fuel used * Fuel price) * Number of travelers affected.

When a road is closed, travelers mostly followed the detours that take longer travel distance to reach the destination. Costs of outages can be estimated by the impact of the detour on travelers. The closure of NH-58 at Kaliasaur slide, forced the travelers to detour through by-pass: Khedakhal- Kandai having distance around 28km (Fig 13). To calculate the cost of this detour, we examined traffic pattern along the highway and estimated the average daily traffic (ADT). By putting the required values of parameters mention in above equation, the total detouring cost for 45 days (approx.) during September-October, 2010 was Rs 2, 45, 43,180 or 25 million Indian currencies. This indirect cost of detour is still a low estimate as it does not include other business ramifications from loss of access to local resources and an associated loss of business at local shops, restaurants, tourist sites, and hotels. This example of the indirect cost of the detour illustrates a relatively simple application of the unit cost method for highway closure impacts in Kaliasaur area.

GEOTECHNICAL INVESTIGATION

In order to predict the landslide occurrence, a quantitative assessment of stability of slope is vital. GEO-5, stability analysis software, was used in the analysis and stability of the slope was determined as per Bishop Method and Patterson method. But, whatever be the method of analysis, choosing proper input parameters is an important step in slope stability analysis. These input parameters include shear strength of the soil, bulk density and degree of saturation for different subsoil layers. The stability analysis of main slide and new slide has been carried out under dry and saturation conditions. The area comes under high seismic zone the stability analysis considers the seismic factors also.

The stability analysis has been carried out by using GEO-5 software. The stability analysis carried out on the global profile to check the stability of the whole slope applying seismic and non-seismic options. Overall stability, after hundreds of iterations, has come closer to 1.28. This was the minimum which has been indicated after all the iterations. Since the slide is active the factor of safety does not prove indicative of all the sensitive local slopes which are actually failing. Therefore local stability analysis was also performed.
The main trouble area from where continuous sliding of varying magnitude has been taking place is identified as a steep crest part. The section for the local stability therefore was selected through the main crest portion. The analysis, after numerous iterations and options, has shown that this part is unstable and the Factor of safety came closer to 0.92. To improve the stability stabilization measures were opted in

view of: (a) the difficult terrain conditions; (b) history of the sliding; (c) mechanism of the failure and other prevailing conditions which could prove to be beneficial for the stability of the slope with viable economic considerations.

REMEDIAL MEASURES

Since at this location the main problem is of rock and debris fall of the fractured rock and over burden material, it was thought to prevent the failing mass so that it does not come on the highway and also doesn't damage the slope. Therefore, the steep face, crest, which is vulnerable for sudden detachment of rocks, is required to be treated for prevention of dislodged rock falling from crest. A scheme of suitable remedial measures for stabilization of slope is presented in fig 14. It is suggested to cover the slope with a steel rope net of

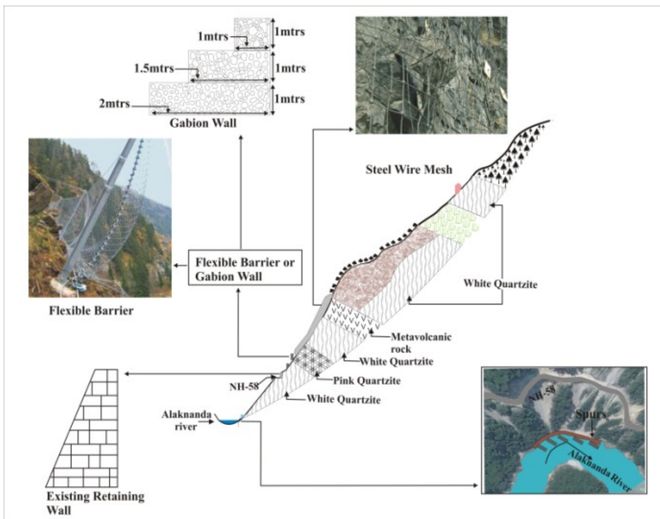

Fig. 14. A Scheme of Remedial Measures for Stabilization of Slope (Pre 2010 Reactivation)

aperture size 300mm X 300mm to stabilize the steep crest part. This kind of stabilization is not intended to avoid the movement of blocks, but will control rocks/debris from falling/bouncing/rolling on the surface of the slope downhill and avoid damaging highway. This will help in uninterrupted maintenance of the highway and minimizing the risk to the travelling public and property (CRRI Report 2012).

CONCLUSION

The investigation and analysis carried out in the study area helped to understand causes and mechanism of the failure of slope and also the most suitable ways of the long term prevention/protection. The gaps on the geological, geomorphological and other aspects have been minimized. The geological and geomorphological assessment of the Kaliasaur landslide facilitated to recognize the weak zones and their inherent characteristics which made the slope vulnerable to slide and thus led the path for providing suitable remedial measures. Although the suggested preventive measures couldn't be applied due to recent reactivation of slide during 2010, it was clearly brought out that to adopt measures which could prevent the sliding material to affect the highway and vehicle and human life had shred those measures due to its reactivation. A part of socio-economic losses on account of landslide have been highlighted so that the planners, maintenance agencies and the general public gets aware of the importance of the pre and post disaster planning aspects.

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